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Creaky Voice in a Pre-Babbling Infant

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Abstract

Creaky voice was examined in an infant at 3 and 4 months. Mean duration of utterances was measured at 3 and 4 months. No occurrences of creaky voice were found at 3 months. Several creaky voice samples were seen at 4 months. Mean duration of creaky voice phonation was determined at 4 months. Frequency and amplitude of the first three harmonics were measured from the creaky voice samples. A raise in amplitude from the first to the second and third harmonics was found. Explanations of infant creaky voice characteristics are offered with respect to possible constraints and affordances allowed at 3 months and at 4 months. Specifically, development of the control of sub-glottal air pressure is implicated in the emergence of creaky phonation at 4 months. Some qualitative comparisons are made between infant creaky voice and adult creaky voice.

Creaky Voice in a Pre-Babbling Infant

The purpose of the present study was to examine the emergence of creaky voice phonation in an infant. Infant language development is generally well understood both in the domain of psychology and linguistics. The literature is growing with respect to infant speech perception and the possible role of speech perception in the development of speech production in an infant's natural language environment (Clement, Koopmans-van Beinum, & Pols, 1999; DeCasper & Spence, 1986; Kuhl & Meltzoff, 1996; Kuhl, Williams, Lacerda, Stevens & Lindblom, 1992; Werker & Stager, 1997). Categorical perception of vowel sounds is present in infants in the first month (Gopnik, Meltzoff, & Kuhl, 1999). Categorical perception is the ability to hear a difference in the sounds of all the languages of the world, including ones that infants have never heard before (Lieberman & Blumstein, 1988). Kuhl et al. (1992) also showed that infants categorize sounds in a language-specific manner as early as six months, losing the distinction between sounds not heard in their own language environments. Furthermore, the infant cochlea has developed to adult-like structures by the third trimester, with mature synaptic connections present by about 24-28 weeks gestation (Pujol, 1991). Therefore, the use of hearing as an aid in developing sound production is probable.

It has been shown that hearing impaired and normally hearing infants show few differences in variation of fundamental frequency over an utterance until about the age of 8.5 months, when their fundamental frequency tends to be higher compared with normally hearing infants (Clement, Koopmans-van Beinum et al., 1999). At this point, hearing impaired infants also start to show an increase in articulations with no voicing. Furthermore, they demonstrate a shorter duration of utterances at about 3.5 months, but not after (Clement, Koopmans-van Beinum et al., 1999). This peak in utterance duration coincides with the age when infants start to gain control of sub-glottal air pressure. At about 3 months, the rib cages of infants have developed to adult-like configurations, in addition to the necessary neuromuscular control of the intercostal and diaphragm muscles emerging (Lieberman, 1986). Lieberman (1986) suggests that, at this age, voluntary phonation over more sustained periods of time become possible. He further suggests that there may be a critical period during which an infant needs to exercise this sub-glottal air pressure and laryngeal control. If not exercised during this period, deficits in phonatory control may result (Lieberman, 1986). The implications of these findings are that hearing seems to play at least some role in the development of sound production of infants, at least at this stage in development. However, little is known about the emergence of specific types of phonation, especially those that require more specific airstream control, i.e. creaky voice.

Infants produce sounds before the babbling stage. The types of sounds produced tend to be harder to classify, especially with complicated differences in voice quality found in infant vocalizations; the vocal tract of an infant is not simply a smaller version of the adult’s, but instead has a very different configuration (Kent & Vorperian, 1995). The infant vocal tract resembles more of a gently curving arc, while the adult configuration makes a right-angle turn at the oropharyngeal conduit, making a sharp turn at the craniovertebral junction (Kent &Vorperian, 1995). Also, the larynx is higher in the neck than the adult larynx (Kent &Vorperian, 1995). Perhaps most notably, the pharyngeal space is undeveloped in comparison with the adult pharynx. In the newborn infant, the epiglottis is in contact with the velopharynx. This configuration changes drastically in the first 6 months, creating a distinctly human pharyngeal space, which may be a large factor in giving humans such a rich phonetic repertoire of speech sounds (Lieberman, 1984). Great difficulties arise when trying to transcribe infant vocalizations using the International Phonetic Alphabet (IPA) and the Extended IPA (ExtIPA), which is used primarily for disordered speech (Esling, Ball, & Dickson, 2000). It has been suggested that the IPA is based on adult-like linguistic phenomenon, and that trying to account for infant speech with the same criteria is ‘nonsensical’ and is ‘shoehorning’ their vocalizations into categories not reflective of their vocal tracts (Nathani & Oller, 2001). Attempts are being made to influence the existing IPA to be modified in order to represent infant vocalizations with infant-like criteria (Nathani & Oller, 2001).

While the order of emergence of consonants in infant speech production is not known exactly, similarities across languages are found in the types of consonants produced at the babbling stage. While no clear view of neurological accounts of speech development exists at present, research has shown some surprising correlations between the onset of babbling in infants and a preference for right-hand manual activity (Locke, Bekken, McMinn-Larson, & Wein, 1995). Babbling typically emerges at about 7-10 months. It is characterized as a repetitive activity involving raising and lowering the mandible, with the lips and tongue creating specific points of obstruction in the vocal tract, thus spectrally shaping the sound (MacNeilage & Davis, 1993). With vocalization, the infant gives the impression of creating a reduplicated syllable (e.g. *bababa*). These vocalizations have adult-like spectral (Oller, 1986) and temporal properties (Kent & Bauer, 1985); they are often mistaken by parents as the child’s first words. The findings of Locke et al. (1995) suggest that both the onset of babbling, which is a very speech-like activity, and the right-hand motor preference become lateralized in the left hemisphere at about the same time. The simple fact that all babies babble suggests that speech, as a human trait, is unsuppressible. This implies that speech, or at least aspects of it, emerge in relation to human physiological development.

However, babies produce vocalizations long before the babbling stage, with cooing seen at about two months (Sachs, 1997). Anatomical characteristics of the human speech apparatus have evolved to enable us to have the greatest range of speech sounds in the animal kingdom. There is debate over whether these speech sounds emerge in an order that represents our evolutionary development. MacNeilage et al. (2000) have provided us with convincing arguments that specific speech sounds in babbling infants emerge at periods when their vocal tracts are primed to do so. They further theorize that these developmental stages may reflect stages in the evolutionary development of man, and thus our speech abilities (MacNeilage, Davis, Kinney, & Matyear, 2000). However, the notion that the speech development of human babies represents a primitive mechanism seems to oversimplify the immense linguistic changes that occur spontaneously, obviously due to genetically endowed skills.

Phonation types are used in some languages to signal a contrast in meaning. Some languages in India (e.g. Gujarati) use breathy voice (murmur) phonemically with vowels (Ladefoged, 1993). Breathy voice requires a relatively high rate of air to produce. Creaky voice, or laryngealized voice, is used by Hausa and many other Chadic languages of North Africa to denote meaning with [j] and, more commonly, with voiced stops [b, d] (Ladefoged, 1993). The creaky voicing is not heard so much in the consonant as in the following vowel, but it is associated with the stop consonant. Similar sounds also occur in some American Indian languages (Ladefoged, 1993). The fact that these phonation types are phonemic in languages implies that infants in those linguistic environments must internalize the acoustic information of such phonation types in order to be able to acquire a phonemic inventory in those languages and be productive speakers. Infants must therefore also learn to produce various types of phonation types, as they first learn new sounds.

Creaky voice is produced by a combination of a specific laryngeal setting and a decreased sub-glottal air pressure. In order to produce creaky voice over any prolonged period of time (e.g. more than 1000 milliseconds) control of the sub-glottal airflow during phonation is absolutely necessary. As infants do not demonstrate control of sub-glottal air pressure until about 3 months (Lieberman, 1986), it follows that they would not have sufficient control to be able to produce voluntary episodes of creaky voice phonation for any significant durations of time.

An infant has not developed control of phonation sufficiently to vocalize unless he is lying down until the fourth or fifth month (Boysson-Bardies, 1999). Respiratory control must also be considered in phonation at this age. Lieberman (1986) suggests that the *breath-group* – the primary element used to segment airflow into sentence-like utterances – can be seen in the initial cries of a newborn, despite a lack of voluntary control until later in development. He further suggests that, although infants cannot control their respiratory system enough to create long breath-groups, they can use their abdominal muscles to create enough subglottal pressure for short bursts of phonation. It is not until about the third month that human infants develop adult-like configuration of the rib cage to be able to produce long episodes of phonation. This includes muscular control of the diaphragm and the intercostal muscles. Creaky voice is a phonation type involving, among other things, specific control of subglottal air pressure (Laver, 1980). It follows that an infant should not be able to produce prolonged periods of creaky voice until about 3 months.

The present study examines phonetic characteristics of the first occurrences of creaky voice phonation in an infant at 3 to 4 months. If the emergence of speech sounds occurs in a classificatory way, with both limitations and affordances created by each stage of development, then it seems reasonable that the emergence of phonation types may similarly emerge in a chronological order, as innervation and structural changes afford such laryngeal control.

Method

Participants

Two subjects were involved in this study. First, naturalistic observations of a male infant were collected during the first 4 months. The recordings were captured in as natural an environment as possible in the home. Second, the adult voice samples were collected from the experimenter, a 32-year-old male with experience in producing creaky voice phonation.

Materials

With respect to the infant subject, the data were video-recorded using a Sony Handycam Video 8, Model no. CCD-TRV37. A logbook of notable linguistic events was kept, especially with regard to the onset of specific types of sounds, both segmental and suprasegmental. Some of the consonants produced at various stages in development were also transcribed.

Procedure

At about 4 months, an abrupt emergence in the production of creaky voice register over sustained periods of time was noticed. In order to examine the data, the audio signal was first edited into an analyzable speech waveform. Later in the experiment, the infant data were compared with samples of an adult male voice, captured with a microphone and converted to a digital signal using the same speech software.

The audio/video signal was converted from the video camera to an audio only signal, and the analog signal was converted to digital using a Roland ED UA-30 USB Audio Interface. The computer used for this experiment was an IBM-PC Pentium III Sony computer. The audio only signal was captured from the camera using Cool Edit Pro LE, manufactured by Syntrillium Software. The software used to edit and perform acoustic analyses of the voice samples was the MultiSpeech program Model 3700 (version 2.2) developed by Kay Elemetrics and Speech Technology Research, Ltd.

Quantitative acoustic parameters being measured from the data included duration of the creaky voice quality over an utterance (measured in seconds) and fundamental frequency and its rate of change over time. Analysis of the fundamental frequency was performed first, then measuring the duration of creaky voice phonation from the spectrogram. As frequency alone is not sufficient in describing creaky phonation, the type of aperiodicity that accompanies vocal fry was also described. This aperiodicity is due to the relaxed state of the anterior portions of the true vocal folds in a reduced eggressive airflow environment, and the involvement of the false vocal folds, or ventricular folds (Laver, 1980). Finally, the infant data were qualitatively compared with samples of an adult male voice producing creaky voice.

Results

Mean duration of utterance was measured for the 10 occurrences of creaky voice phonation found at 4 months of age. Utterances containing creaky voice phonation were calculated to be a mean duration of 1.95 seconds, with a range from 1.018 seconds to 3.461 seconds. Mean duration of creaky voice phonation within each utterance at 4 months was also calculated. Creaky voice phonation within the 10 utterances at 4 months was calculated to be a mean duration of 1.43 seconds, with a range of 0.4133 seconds to 3.461 seconds.

No utterances of creaky voice were observed at 3 months. From the data set, eleven utterances were found at exactly 3 months. The mean duration of these utterances at 3 months was 1.199 seconds, with a range of 0.248 seconds to 2.248 seconds. Figure 1 shows these values graphically.

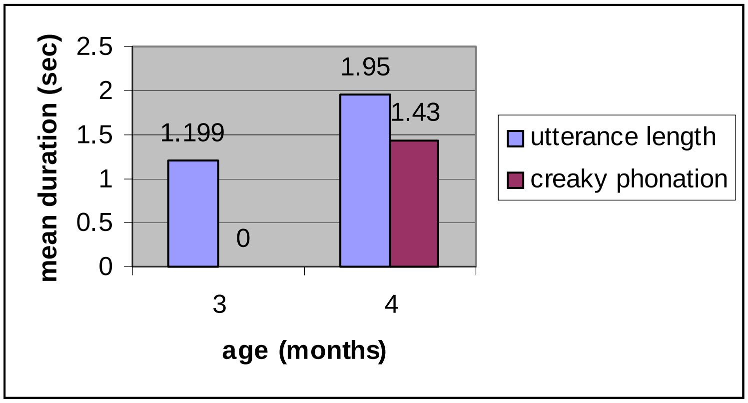


Figure 1. Duration of utterances and creaky phonation in an infant at 3 and 4 months.

The amplitude and frequency of the first 3 harmonics during creaky voice utterances at 4 months is shown in Table 1. Power spectrum analysis size was 2048 points.

Table 1

Amplitudes and Frequencies of First 3 Harmonics in Creaky Voice at 4 Months of Age

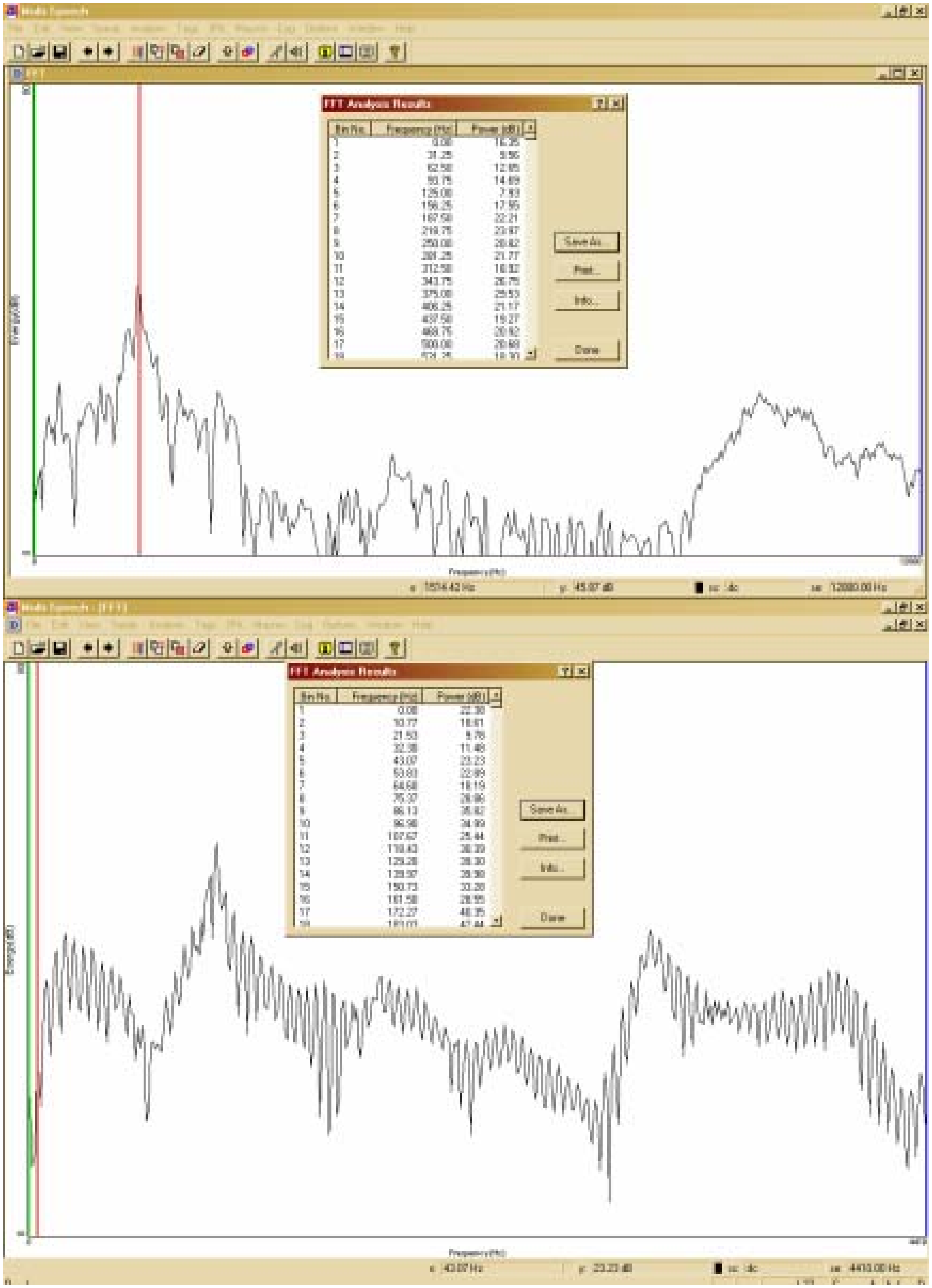
Utterance #		1st Harmonic	2nd Harmonic	3rd Harmonic
1	Freq. (Hz)	31.25 Hz	62.50 Hz	125.00 Hz
	Amp. (dB)	0.10 dB	6.75 dB	10.48 dB
2		78.13 Hz	125.00 Hz	171.88 Hz
		4.93 dB	4.15 dB	20.23 dB
3		46.88 Hz	78.13 Hz	216.49 Hz
		8.51 dB	7.08 dB	20.72 dB
4		46.88 Hz	125.00 Hz	324.38 Hz
		19.89 dB	21.07 dB	32.43 dB
5		46.88 Hz	109.38 Hz	156.25 Hz
		18.08 dB	17.49 dB	12.02 dB
6		54.12 Hz	93.75 Hz	125.00 Hz
		12.25 dB	6.99 dB	9.35 dB
7		57.14 Hz	109.38 Hz	187.50 Hz
		3.77 dB	6.67 dB	22.76 dB
8		28.57 Hz	62.50 Hz	218.75 Hz
		15.72 dB	14.14 dB	28.01 dB
9		31.25 Hz	125.00 Hz	203.13 Hz
		21.10 dB	19.56 dB	30.04 dB
10		28.57 Hz	109.38 Hz	218.75 Hz
		13.82 dB	11.51 dB	27.06 dB

Note. Mean frequency of first harmonic during creaky phonation was calculated to be 44.97 Hz.

Discussion

The duration of the infant’s utterances were on average longer at 4 months than at 3 months, with utterances produced as long as 3.461 seconds. This finding is consistent with the notion that sufficient laryngeal control and sub-glottal air pressure to control phonation emerges at about 3.5 months. In the data collected at 3 months, no occurrences of creaky voice were seen. This may be because the sub-glottal pressure control needed to produce creaky voice, i.e. with a sustained low airflow, has not yet emerged.

Power spectra of the waveforms tended to show an interesting acoustic effect of the aperiodicity caused by the stiffness and thickness of the vocal folds and the involvement of the false vocal folds. The first harmonic showed lower amplitude than the next two harmonics. In the creaky voice samples, the first harmonics did not contain the most energy. This is supported by Monsen and Engebretson’s suggestion that creaky voice is the least sinusoidal of all phonation types (as cited in Laver, 1980). In contrast to modal voice, where the first harmonic tends to dominate the spectrum, creaky voice shows a higher amplitude in the second, third and fourth harmonics. Also, when the frequency during creaky voice was lower, the spacing of the first 3 harmonics was wider. These patterns are shown in the Fast Fourier Transform (FFT) analyses in Figure 2. Comparisons can be made between an infant and an adult speaker. While the infant FFT showed the same pattern of higher second and third harmonics, all harmonics tended to be lower in energy compared with the adult. This could be due to a weaker signal at the time of capture (the infant speech was captured by video, the adult was captured by a microphone), or a reduced airflow in the infant.



Bin No.	Frequency (Hz)	Power (dB)
1	0.00	16.35
2	31.25	9.56
3	62.50	12.85
4	93.75	14.69
5	125.00	7.93
6	156.25	17.55
7	187.50	22.21
8	218.75	23.87
9	250.00	20.82
10	281.25	21.77
11	312.50	18.82
12	343.75	26.75
13	375.00	25.53
14	406.25	21.17
15	437.50	19.27
16	468.75	20.92
17	500.00	20.68

x: 1514.42 Hz y: 45.07 dB sc: dc sx: 12000.00 Hz

Bin No.	Frequency (Hz)	Power (dB)
1	0.00	22.30
2	10.77	18.81
3	21.53	8.76
4	32.30	11.48
5	43.07	23.23
6	53.83	22.89
7	64.60	18.19
8	75.37	26.86
9	86.13	35.82
10	96.90	34.99
11	107.67	25.44
12	118.43	38.39
13	129.20	38.30
14	139.97	38.90
15	150.73	33.28
16	161.50	28.95
17	172.27	40.35

x: 43.07 Hz y: 23.23 dB sc: dc sx: 4410.00 Hz

Figure 2. FFT of creaky voice in a 4-month-old infant and a 32-year-old male.

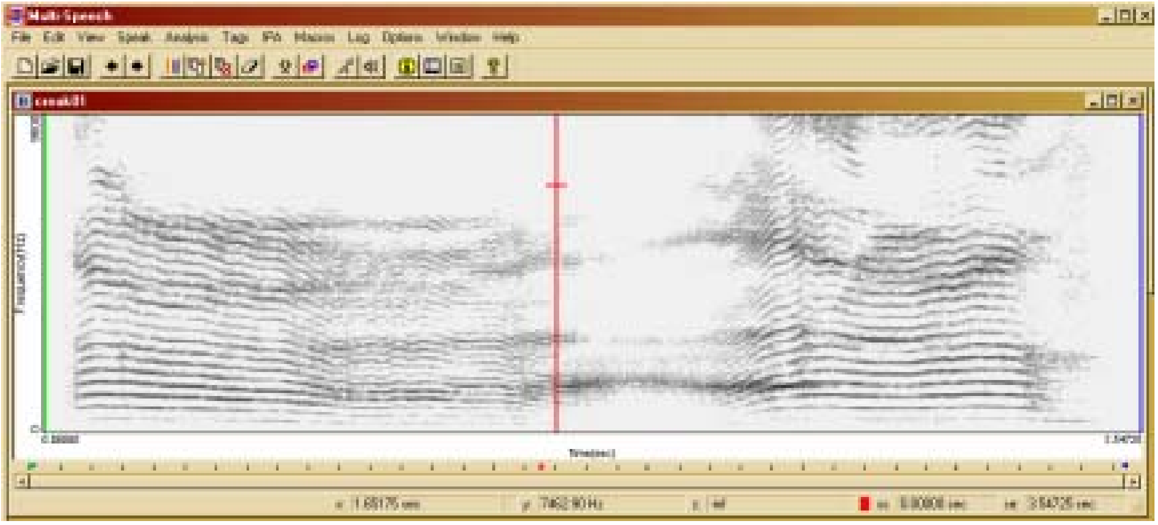


Figure 3. Narrow band spectrogram of creaky voice at 4 months.

The most interesting thing noticed was how the individual harmonics seemed to decrease in frequency until the creaky phonation started (where the harmonics enter a period of fluctuation before the red line). Figure 3 also shows how the glottal spectrum of creaky voice is maintained during the period of creak (Laver, 1980). During the period of creaky voice, weak formants can be seen around the frequencies that had comprised the first and second and even third formants during modal voice. However, they appear to have collapsed into a larger concentration of energy at lower frequencies. The harmonics visible during creaky phonation are weak and reduced, presumably due to the diminished airflow and sub-glottal pressure. This pattern can also be seen in Figure 4 – a similar sample of creaky voice by an adult speaker.

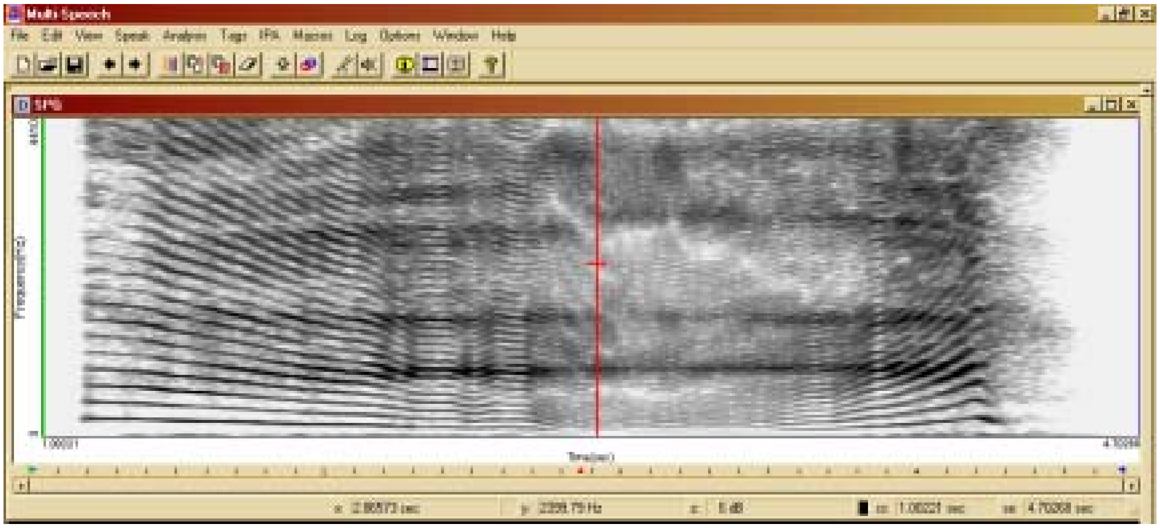


Figure 4. Narrow band spectrogram of creaky voice in a male adult speaker.

Interesting to note is the apparent loss of periodicity, seen in the period where the individual harmonics disappear. This could be due to the interaction of the ventricular folds. Recall that the ventricular folds during creaky voice depress down onto the vocal folds especially at posterior regions in order to stabilize the posterior area of the glottis and allowing sub-glottal air to pass the glottis in the anterior regions of the glottis.

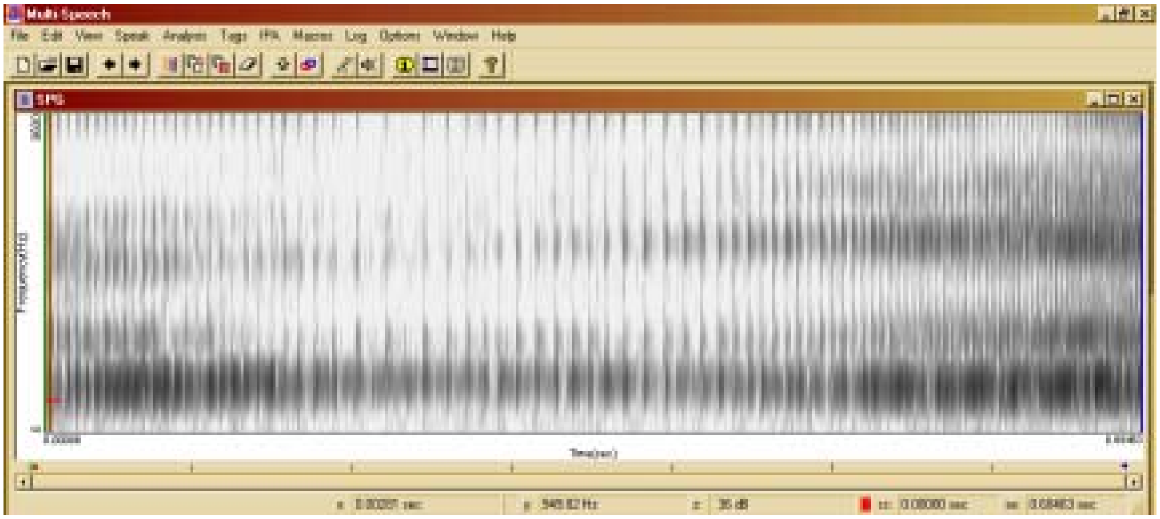


Figure 5. Wide band spectrogram of creaky voice at 4 months.

The spectrogram in Figure 5 shows the opening and closing of the infant's glottis. Notice how the period of opening and closing is shorter initially, but the frequency drops during the production of creaky voice. The vertical striations on the spectrogram represent the open phases of the glottis as the acoustic energy is passing through the vocal folds. Furthermore, the irregularity of the frequency can be seen, as no constant opening-and-closing rate can be detected.

In the utterance displayed in Figure 6, there is a distinct period of a complete cessation of airflow (immediately after the red line). In manipulating the amount of airflow typically accompanying creaky phonation, i.e. decreasing airflow, the infant at 4 months seems to exhibit an ability to control musculature involved in this process – abdominal muscles. This was confirmed by evaluating the corresponding video footage for this sample.

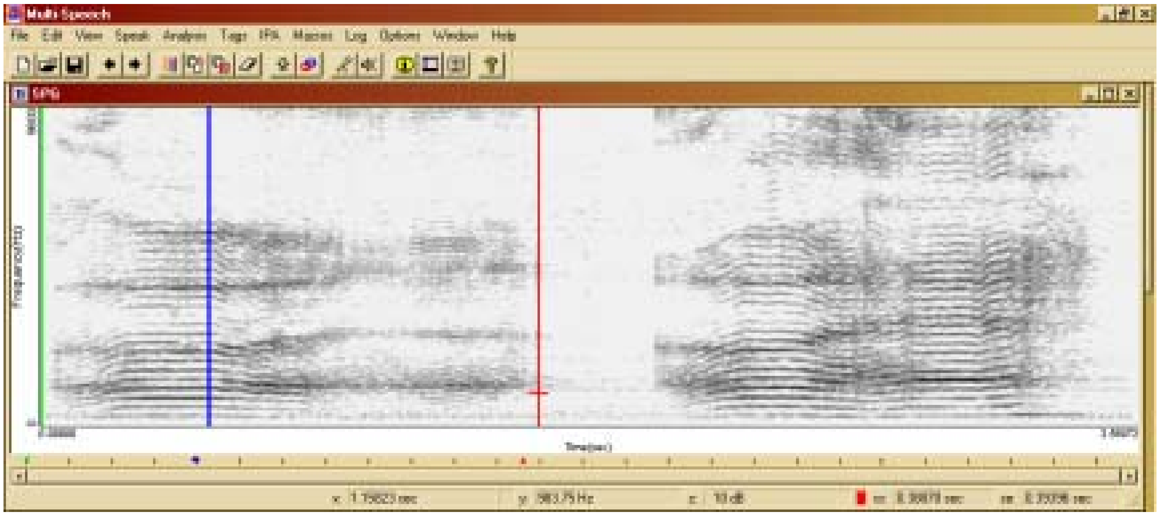


Figure 6. Narrow band spectrogram of creaky voice at 4 months.

Here, the infant was decreasing airflow in vocal play. The result was a constant drop in frequency, and amplitude. This can be seen in Figure 6, where the individual harmonics begin to decrease in frequency and intensity over the first segment (at the blue line), and then enter a period where they seem to fluctuate and eventually disappear (at the red line). This point is essentially a glottal stop, with complete closure at the glottis, followed by a release burst. The measured duration of this period of complete closure was 0.280 seconds. It could be said that, essentially, the fundamental frequency – the rate of opening and closing of the glottis – dropped to zero during this period.

The transition back to modal voice happens more slowly than it would in normal adult speech, as he seems to be exploring the vocal effects of adjusting the airflow. The frequency of harmonics and intensity both return to modal voice settings in part by a rapid increase in airflow. Presumably, a return to modal-like laryngeal settings also accompanies this transition. This would include a release of the ventricular folds holding the vocal folds in their stop position, as well as a slight relaxation of the posterior regions of the vocal ligaments, allowing them to vibrate more rapidly with the increased airflow.

In comparing the infant creaky voice spectrogram with that of the adult, some patterns can be seen. First, the adult samples consistently contained more energy. This can be seen on the spectrograms, as adult formants were much darker and more defined than those of the infant. While the media through which the samples were captured were different, this is not surprising considering the larger air volume available to the adult. The waveform in the adult is more periodic than that of the infant, even during creaky voice. This also seems logical, considering the better control of sub-glottal pressure as well as an experienced laryngeal control over the musculature involved in all speech, including creaky voice. The infant at 4 months has just acquired this ability.

The shape of the waveform during each opening of the glottis in both the infant and the adult samples shows an interesting pattern. Each oscillation (in creak) forms a narrow triangular shape. This can be seen in Figures 7 and 8, where the waveforms of the infant and adult are compared, along with their corresponding wide band spectrograms.

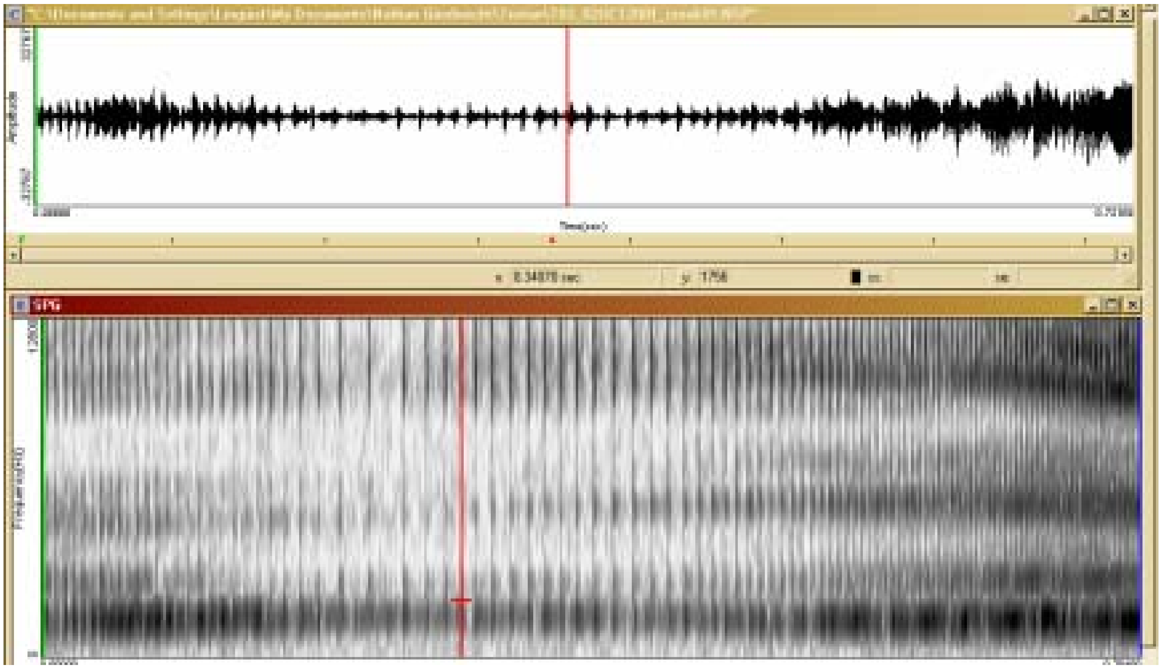


Figure 7. Wide band spectrogram of creaky voice in a 4-month-old infant.

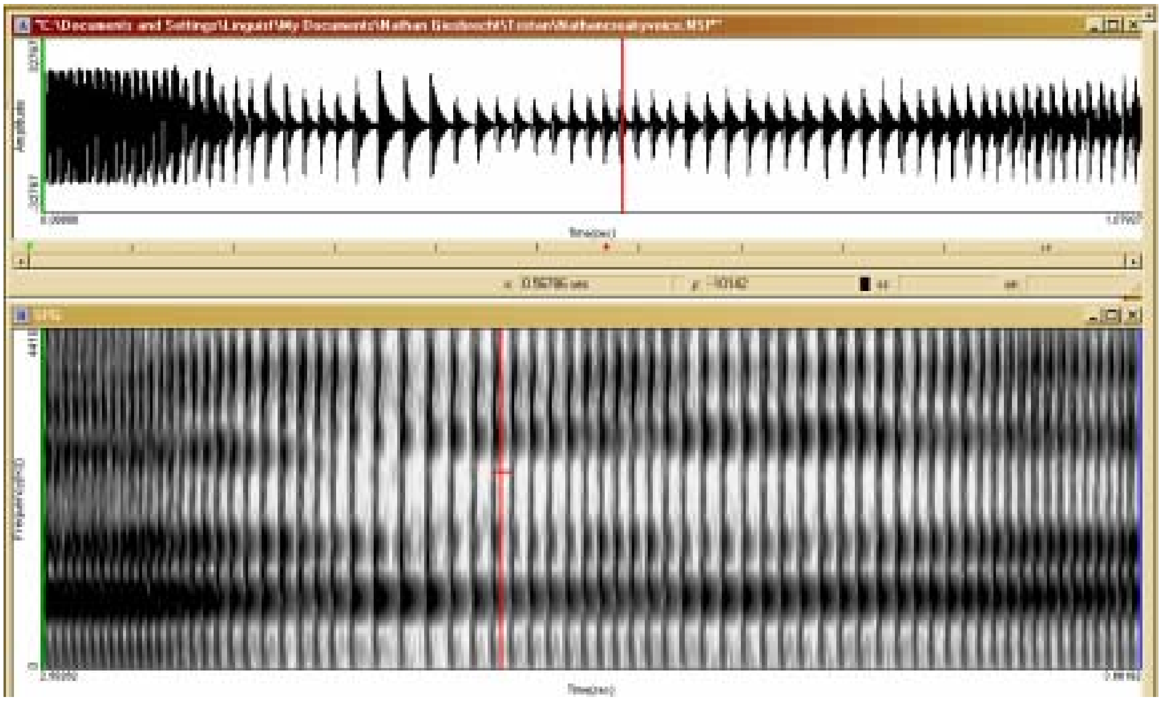


Figure 8. Wide band spectrogram of creaky voice in a 32-year-old male.

The energy is greatest at the point where the glottis opens first, while it decreases steadily until the next closure, and then peaks again. This burst of energy immediately after the opening of the glottis is due the manner of production of creaky voice. During creaky voice, the vocal folds are strongly adducted – brought together – but are of a weak longitudinal tension. They also are in contact with the false vocal folds. This increased mass and weak longitudinal tension creates an unusually thick and slack structure. Thus when the sub-glottal air pressure builds up enough to open the glottis, the air escapes in little bursts each oscillation. As the glottis is in its closing phase, the amplitude on the waveform can be seen to dropping towards the next glottal closure.

Conclusion

The goal of this study was to explore aspects of creaky voice phonation in an infant at 3 months and at 4 months. As was expected, the duration of utterances was longer in the infant at 4 months than at 3 months. Also, as claimed by Lieberman (1986), that control of sub-glottal pressure is not sufficiently developed until about 3.5 months, creaky voice phonation was not found in the data until 4 months. This corresponds with an undeveloped pulmonic control, specifically the structural development of the ribcage to adult-like structure and voluntary neural control of the diaphragm and intercostal muscles that are necessary to reduce eggressive airflow for sustained periods, such as in the production of creaky phonation. The acoustic characteristics of infant creaky voice very closely resemble those of the adult, with lower amplitude seen at lower frequency utterances. Infants may be producing various phonation types even before they can produce speech segments (vowels and consonants). The acquisition of phonation control is paramount to speech production in general, and may even become an important phonemic representation in certain languages. The emergence of creaky voice in an infant was found approximately to coincide with the age of normal development of the necessary physiological control suggesting that the development of speech is constrained by the limits of the vocal apparatus at given stages.

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